

Holston Army Ammunition Plant,
RDX-and-Composition-B Manufacturing Line 9
(Holston Ordnance Works)
Plant B (Area B)
Vicinity of Kingsport
Hawkins County
Tennessee

HAER No. TN-10B

HAER
TENN,
82-KINPO,
2-B-

PHOTOGRAPHS

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WRITTEN HISTORICAL DATA

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HISTORIC AMERICAN ENGINEERING RECORD

HOLSTON ARMY AMMUNITION PLANT,
RDX-AND-COMPOSITION-B MANUFACTURING LINE 9
(HOLTON ORDNANCE WORKS)
HAER No. TN-10B

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TENN,
82-KINPO,
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Location: Plant B (Area B),
Holston Army Ammunition Plant,
Vicinity of Kingsport,
Hawkins County, Tennessee.
UTM: 17.355000.4044120
17.354580.4043420
Quad: Kingsport, Tennessee-Virginia

Date of Construction: 1942-1944

Present Owner and Occupant: U.S. Army

Present Use: Explosives manufacturing

Significance: Line 9 is highly representative of the 10 production lines constructed at Holston Army Ammunition Plant (HSAAP) during World War II for the manufacture of the military high explosive Composition B, and its chief ingredient RDX. These buildings embodied the world's first, large-scale, industrial application of the "Bachmann method," which revolutionized the production of RDX by replacing an expensive, labor-intensive batch technology with a cost-efficient, mass-production operation. The HSAAP manufacturing lines also greatly improved on previous procedures for producing Composition B.

During World War II, HSAAP was the only American, Bachmann-method plant, accounting for approximately ninety percent of the country's output of Composition B, which was extensively used in Allied naval ordnance. Neither the Germans nor Japanese possessed as powerful an explosive. The large volume of Composition B manufactured at HSAAP significantly contributed to Allied victory in the Battle of the Atlantic and helped pave the way for the liberation of the Continent.

Historian: Jeffrey A. Hess, April 1986

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SITE ORIENTATION

Holston Army Ammunition Plant (HSAAP) is a government-owned, contractor-operated installation constructed during 1942-1944 for the manufacture of the military, high explosive Composition B and its chief ingredient RDX. The installation consists of two separate plants -- "Area A" and "Area B" -- located about four air miles apart on the Holston River in northeastern Tennessee¹ (see HAER Photo Nos. TN-10A-12, TN-10A-13). The two plants are connected by above-ground chemical pipelines and an inter-plant railroad. Area A presently occupies about 120 acres in the heart of the manufacturing district of the City of Kingsport in Sullivan County. It produces raw materials for, and processes by-products from, Area B, which is situated westward and upstream on about 5,900 acres in rural-suburban Hawkins County.

Area B is bounded on the north by U.S. Highway 11W, which provides immediate access to HSAAP's main administration buildings. About one-half mile south of this office complex is the RDX-and-Composition-B manufacturing district, occupying a level plain bordered on the east and south by the Holston River. The district contains 10, nearly identical, parallel, manufacturing lines spaced about 500 feet apart and serially designated, from west to east, as "Line 1" through "Line 10" (see HAER Photo Nos. TN-10B-24, TN-10B-25, TN-10A-12, TN-10A-13). A typical line consists of a more-or-less linear arrangement of 12 buildings, extending about one-half mile from north to south. Beginning with "C" on the north and concluding with "N" on the south,

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the buildings are designated alphabetically, with a numerical suffix added to identify the particular line. Building C-1, for example, is the first building in Line 1; Building N-10 is the last in Line 10.²

The subject of the present study is Line 9, which offers the closest approximation to the World-War-II manufacturing process. Placed in operation in November 1943, it was one of the last lines completed,³ incorporating most of the major process refinements developed at HSAAP during World War II. Deactivated in July 1945, the line remained closed until the late 1960s, when it was reactivated and partially remodeled for the Vietnam War. Inactive since 1973, Line 9 has not been affected by the post-Vietnam modernization programs that have altered the equipment of several other lines.⁴ Although Line 9 no longer retains a full schedule of production equipment, it preserves the basic outlines of the World-War-II process, as modified during the late 1960s. Before looking more closely at the line's technology, it would be helpful to consider the general historical background of HSAAP and the development of RDX-based explosives.

HISTORICAL BACKGROUND

In June 1940, shortly after the fall of France, President Roosevelt established the National Defense Research Committee (NDRC) to mobilize the nation's academic community for "research on the mechanisms and devices of warfare." In time, the NDRC would sponsor hundreds of research projects running the

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gamut from amphibious vehicles to rocket propellants. But initially it focused its attention on promising new technologies developed by the British, and this was particularly true in the area of high explosives.⁵

During the 1930's, British strategists had learned that German submarine hulls were being strengthened to withstand anything short of a direct hit by a conventional, TNT-loaded depth charge. To counter the U-boat threat, the British Admiralty began seeking a more effective explosive, and its first choice was cyclonite. Discovered as early as 1899, cyclonite was known to be almost twice as powerful as TNT -- but also several times more sensitive to shock, which precluded its use in conventional ordnance. By the late 1930's, however, British scientists at the Armament Research Department at Woolwich Arsenal had determined that cyclonite could be sufficiently desensitized for munitions by combining it with wax, plasticizing oils, or TNT. As a security measure, the British rechristened cyclonite as "Research Department Explosive," or RDX. With a similar flair for anonymity, they chose the name of "Composition B" for the desensitized mixture of RDX (60%), TNT (40%), and wax (about 1%) that was to be widely used in Allied naval ordnance during World War II.⁶

For its most typical combat use, Composition B was combined with aluminum powder at specialized "loading plants" to form the explosive "Torpex," which was particularly effective in torpedos and depth charges. Indeed, Torpex torpedos were of such supreme strategic importance that they were carefully

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rationed by the Allies during the early years of the war:

Originally issued to submarines with the best record of kills, the new product was distributed throughout the submarine fleet as fast as production permitted. Ship sinkings increased, and [reports were received] that Torpex torpedos were able to break vessels in two. Comparative tests with captured enemy munitions showed that neither the Germans nor the Japanese possessed explosives as powerful as Torpex.

Composition B played a particularly crucial role "in winning the Battle of the Atlantic, [which was] acknowledged by both the United Nations and the Axis alike as the most important single phase of the war." Composition B also "in great measure paved the way for the invasion of the European continent and for the final destruction of the Japanese war effort."⁸

Although the British were the first to tame cyclonite, they were less successful in devising an efficient means for mass producing it. The method developed at Woolwich Arsenal, and first employed on a large scale at Bridgewater, England in the summer of 1941, involved a simple batch process for the nitration of hexamine by concentrated nitric acid. Calling for eleven pounds of strong nitric acid for every pound of RDX produced, the Woolwich method required the construction of an enormous, on-site, nitric-acid works, which made the process extremely expensive to implement and operate. While the Bridgewater plant was still under construction, the British encouraged the newly created NDRC to investigate a cheaper method of manufacturing RDX. The NDRC took up the challenge, and in November 1940, it selected Werner E. Bachmann, an organic chemist at the University of Michigan, to work on the project.⁹

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Bachmann had no previous experience with munitions, and as he later declared, his "heart sank" at the prospect of working on an explosives project. Despite his personal distaste for the work, Bachmann threw himself into the study with such energy that within three months he had developed a new RDX-production process, involving the nitration of hexamine by a mixture of strong nitric acid and ammonium nitrate, with acetic anhydride added to serve as a dehydrating agent that drove the reaction to completion. Bachmann's discovery reduced the total nitric-acid requirements of the Woolwich method by fully 85% while doubling the RDX yield from hexamine. The new process, however, did have one drawback: it released, as a by-product, substantial quantities of weak acetic acid contaminated with RDX. Before the Bachmann method could become a practical manufacturing technique, it was necessary to devise a means of purifying the acetic acid, concentrating it, and reconvertng it to acetic anhydride. The search for the solution to this problem led the NDRC to the Tennessee Eastman Corporation of Kingsport, Tennessee.¹⁰

A wholly-owned subsidiary of the Eastman Kodak Company of Rochester, New York, the Tennessee Eastman Corporation was a leading producer of both acetic anhydride and cellulose acetate, which it manufactured into synthetic yarn. In developing its cellulose-acetate facility, Tennessee Eastman had engineered an acetic-acid recovery system that seemed applicable to the Bachmann process. In November 1941, the NDRC requested Tennessee Eastman to join its RDX task force, and three months later, the company reported that it had worked out a feasible acid-recovery procedure. The firm was then asked to design and

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operate two pilot plants in Kingsport: one to manufacture RDX according to the Bachmann method, and the other to combine RDX and TNT into Composition B. Both plants were in production by the end of April 1942. Highly impressed with the company's expeditious handling of the pilot projects, the NDRC recommended that Tennessee Eastman be selected to design and operate HSAAP, the country's first and only large-scale, Bachmann-method, RDX installation. A contract to this effect was signed by Tennessee Eastman and the United States government in June 1942.¹¹

The Kingsport area was selected as the site for HSAAP primarily because it was the manufacturing base of the Tennessee Eastman Corporation, which would serve as contractor-operator of the new facility.¹² The site also satisfied the following basic criteria that governed the selection of other World-War-II explosives plants:

- (1) availability of suitable labor without major housing projects;
- (2) proximity to a main railroad line;
- (3) availability of adequate electric power;
- (4) ample supply of water for processing;
- (5) availability of extended, isolated tracts for explosives manufacturing and storage;
- (6) a location at least 200 miles from coastal waters and international borders as a defense against enemy attack.¹³

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When the government began its acquisition of land for HSAAP in the summer of 1942, the Area-A site, immediately adjacent to the Tennessee Eastman Plant in Kingsport, was an unoccupied, industrially-zoned tract with no standing structures. The Area-B site in rural Hawkins County was predominantly crop and pasture land that had long been used for dairying. It contained at least thirty-eight standing structures, including farmhouses, servants' quarters, garages, stables, barns, and a schoolhouse. None of these buildings survive within the present boundaries of HSAAP.¹⁴

Construction work on HSAAP commenced in the summer of 1942, under the general supervision of the U. S. Army Corps of Engineers, which created a special "Holston District" to administer the project. Since HSAAP was the first large-scale facility to implement the Bachmann process, there were no precedents for its overall design. The preparation of engineering and construction specifications was further complicated by a phased completion schedule that called for the progressive activation of production lines. As one engineer on the project observed, "Holston was very literally designed, built and operated simultaneously."¹⁵

The Corps of Engineers launched the project by letting two major contracts. The first went to Tennessee Eastman Corporation for "general layout of the plant, design of the manufacturing buildings, design and procurement of manufacturing equipment, and finally operation of the plant." The second contract was awarded to the New York architectural and engineering firm of

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Fraser-Brace Co., Inc., which had just completed a series of design and construction contracts for the expansion of the Weldon Springs Ordnance Works, a sprawling TNT plant in Missouri. Fraser-Brace agreed to serve as general contractor and project manager, and assumed direct responsibility for "all construction and equipment installation, all procurement (other than manufacturing equipment), and all design of temporary utilities and structures." For its principal subcontractor on the HSAAP project, Fraser-Brace selected the Boston architectural and engineering firm of Charles T. Main, Inc., which had previously handled the construction of Camp Edwards in Massachusetts. At the HSAAP site, the Boston firm was responsible for the "design of roads, railroads, bridges, utilities, magazines and all buildings other than manufacturing, as well as field layout and field inspection."¹⁶ By dividing design responsibility among three firms, the Corps of Engineers had hoped to promote flexibility and speed. In practice, however, the project was plagued by persistent confusion at the construction site, exacerbated by "an element of friction" between Fraser-Brace and its Boston associate.¹⁷

In June 1943, as HSAAP was nearing completion, the War Department authorized a 40-percent increase of the installation's production capacity for Composition B. Two months later, this change order was amended to provide for a 100-percent increase.¹⁸ Since the expanded production quotas necessitated modifications in the original design of buildings and equipment, construction crews remained at the site until mid-March 1944, when "the project was finished, cleaned up and 100% in the hands of the operators."¹⁹ At this time

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the Corps of Engineers took inventory of the new installation and counted a total of 610 buildings. Of this number, 48 were located at Area A, which was primarily responsible for manufacturing acetic anhydride, a basic ingredient for the production of RDX at Area B. The 562 buildings at Area B were congregated by function into administrative, shop, storage, residential, and manufacturing areas²⁰ (see HAER Photo No. TN-~~10B-55~~^{10A-12}).

In terms of overall architectural design, HSAAP reflected both its general industrial function and the no-frills speed of its construction. Almost all the buildings were utilitarian in style without pretense to ornamentation. Perhaps the most striking aspect of the installation was the widespread use of brick, which was generally considered too costly for wartime, munitions-plant construction:

A reinforced-concrete frame and brick wall design was adopted for most of the heavy manufacturing buildings and for the steam plants, primarily to save steel. Several of these buildings might have been built of all concrete, but lumber was exceedingly scarce and brick was used to save not only steel but form lumber. Brick was available in ample quantities for immediate delivery from a plant near Kingsport. An adequate number of capable bricklayers also was available, making cost of brick construction not excessive as compared to frame construction. Consequently, many buildings that normally would have been of frame construction were built of brick. . . .²¹

The most unusual aspect of HSAAP, however, was its chemical engineering. Other World War II explosives plants relied on well established industrial processes. But the preparation of RDX by the Bachmann method was quite another matter. When Tennessee Eastman first began work on a pilot plant for RDX in early 1942, the Bachmann method was a laboratory procedure rather than

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a mass-production technique. In its basic outline, the method called for both dry and liquid ingredients that were reacted in a two-stage, batch process with an intermediate drying period. The resultant RDX was then filtered from solution, purified by washing, and concentrated by drying. All steps were fastidiously done by hand, using standard laboratory glassware. Bachmann himself had "never made more than a few grams of the dangerous stuff."²²

In streamlining this procedure, Tennessee Eastman introduced two important innovations. First, all ingredients were transformed into concurrent liquid feeds that were united in a one-stage, continuous reactor capable of producing a steady flow of RDX. Second, a production system was devised whereby the RDX was transferred from one processing building to another in slurry form through the use of centrifugal pumps. As a result of these innovations, the Bachmann method became a mass-production process, with raw materials entering at one end of a production line, and RDX rolling off at the other.²³

Tennessee Eastman also improved on the standard British method of combining RDX and TNT into Composition B. As one observer noted:

The British procedure for making Composition B was to melt TNT in a heated kettle, shovel in wet RDX and stir until the water evaporated. The molten mix was then poured into trays something like biscuit pans where it cooled and solidified. With only a few pounds per tray, this was a real labor hog. Besides, the workers were constantly exposed to poisonous TNT fumes.²⁴

To speed up the final casting and cooling process, Tennessee Eastman developed a continuous pelleting procedure that used "an agitated casting pot with multiple holes in the bottom" to extrude the warm Composition B mixture onto a

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moving conveyor belt, which cooled the pelleted explosive and dumped it into a packing box. "The process was simple, ingenious and safe. It eliminated the TNT fume problem and reduced labor by a very large factor."²⁵

HSAAP's first production line for RDX and Composition B went into operation in April 1943, and by the end of that year, all ten lines were in production. At peak performance, the installation manufactured 40 million pounds of Composition B per month, and its total wartime output reached nearly one billion pounds. Constant refinements in the overall manufacturing process decreased labor requirements per line from an initial 123 employees to 100 at war's end, while doubling the output of explosive. HSAAP continued to operate at maximum levels until July 1945, when nine of its ten explosives lines were deactivated. Complete shutdown occurred immediately after V-J Day. On November 1, 1945, HSAAP was designated a "standby" facility, and two weeks later, the Tennessee Eastman Corporation turned the installation over to the Ordnance Department for continued maintenance and supervision.²⁶

In April 1949, HSAAP was removed from standby status and reactivated as a production facility under the contract-supervision of the Holston Defense Corporation, a newly formed subsidiary of the Eastman Kodak Company of Rochester, New York. Initially, production activities focused on the reworking of surplus stocks of Composition B, which involved the use of one manufacturing line. But as the Korean War got underway, most of the installation's facilities at Areas A and B were mobilized for new production.

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During 1951-1954, Lines 1-8 were rehabilitated, and in August 1953, production reached a monthly peak of 15.2 million pounds of Composition B.²⁷

For the most part, the basic manufacturing processes developed during World War II continued to govern the installation's operation. The most significant departure occurred at Line 4, which was converted to the manufacture of a new high explosive known as HMX. Nearly identical in chemical structure to RDX, this new nitramine compound is characterized by a higher melting point, which led to its designation as "High Melt Explosive," or HMX. HMX is always produced in minute amounts during the manufacture of RDX by the Bachmann method, and it was first isolated and identified by Bachmann during his experimental work on RDX in 1941-1942. Although HMX was found highly suitable for plastic explosives, it proved too difficult and expensive to manufacture during World War II, and only a pilot production run of 25,000 pounds was attempted at HSAAP before V-J Day. In 1952, however, HSAAP once again took up the production of HMX, and gradually developed a successful batch operation at Line 4 that was quite similar to the general Bachmann method used for RDX manufacture.²⁸

Although HSAAP remained in operation after the Korean War, production was generally restricted to one manufacturing line and rarely exceeded one-half million pounds of Composition B per month. As a result of the Berlin and Cuban crises of the early 1960s, the installation's monthly output increased to about two million pounds, but large-scale production did not resume until

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the Vietnam buildup of the mid-1960s. During 1965-1966, the government appropriated about \$40 million to modernize HSAAP's production equipment and support facilities, and to rehabilitate Production Lines 9 and 10, which had not seen use since World War II. By December 1968, all ten lines were in service, with a combined monthly production of about 33 million pounds of Composition B, which nearly equalled the World-War-II record.²⁹

With the conclusion of the Vietnam War in 1973, the installation's output of Composition B rapidly declined to about two million pounds per month in early 1976. During the late 1970s and early 1980s, further declines in Composition B production were partially offset by increased demand for "special-order" propellants and explosives using RDX and HMX.³⁰ Still an active manufacturing facility supervised by the Holston Defense Corporation, HSAAP retains its strategic importance as the country's sole producer of HMX- and RDX-based propellants and explosives.

PROCESS DESCRIPTION OF LINE 9

Currently in "laid-away" condition, Line 9 has not been in operation since 1973. Although most of its equipment is still in place, some of the apparatus has been at least partially dismantled and other items have been completely removed. During the period of line 9's deactivation, the HSAAP manufacturing process underwent a number of improvements. If Line 9 were to be reactivated, its equipment and former operating procedures would require revamping

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to synchronize with the installation's present manufacturing program. In light of these considerations, any technological description of the line's process flow must, in some degree, present an idealized reconstruction of "how things used to be."

Our discussion is further complicated by the lack of hard data on the number of personnel previously required to operate the line and the specific nature of their duties. Except for a few material handling operations (unloading, weighing, shoveling, etc.), most personnel seem to have been involved in relatively "invisible" tasks, such as reading gauges, recording temperatures, opening and closing valves, activating pumps, and so forth. Since we do not have sufficient information to describe these operations in detail, we will largely omit them, focusing instead on the mechanized flow of materials from one station to another. Although the elimination of the "human element" distorts the manufacturing process, it does have a certain validity for chemical engineering systems, where the major protagonists are chemical reactions, which, once set in motion under prescribed conditions, proceed according to their own molecular logic.

The existing technology of Line 9 is a World-War-II manufacturing operation that was significantly modified in the late 1960s. Proceeding from one building to another, we will discuss both the modified and original process, taking note of general construction details, equipment layout, and innovative chemical engineering.³¹ No attempt will be made to discuss auxilliary

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technologies, such as the manufacture of raw materials and the processing of by-products, which affected the operation of Line 9, but occurred at different areas of the installation³² (see HAER No. TN-10A). In terms of utilities, all of the buildings in Line 9 are supplied with electricity, water, and steam. In addition, all buildings above one-story in height are equipped with metal safety chutes on the upper stories to permit rapid evacuation in case of fire or impending explosion. Unless otherwise noted, it is to be assumed that all equipment is electric-powered.

Building C-9 (Mixing Building)

Bachmann's laboratory procedure for preparing RDX called for four basic ingredients: hexamine, ammonium nitrate, nitric acid, and acetic anhydride. The first two of these chemicals occur naturally as solids; the second two as liquids. In devising a mass-production technique for RDX, Tennessee Eastman consulted with Bachmann, who suggested the conversion of all ingredients into three, separate, liquid feeds. This was accomplished by (1) keeping the acetic anhydride in its natural liquid state, (2) dissolving the ammonium nitrate in the nitric acid, and (3) introducing another liquid chemical, acetic acid, to dissolve the hexamine.³³

In laying out the ten RDX lines at HSAAP, Tennessee Eastman planned for five "Mixing Buildings," one for every two lines. Equidistantly spaced between adjoining lines at the head of the manufacturing area, the Mixing Buildings

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were designed to receive the raw materials, prepare the necessary chemical solutions, and then distribute the liquids to the D Buildings, which were next in line. By having specific Mixing Buildings distribute ingredients only to specific lines, Tennessee Eastman hoped to "simplif[y] the determination of individual line yields."³⁴

During HSAAP's construction, however, an accident occurred at Tennessee Eastman's RDX pilot plant that prompted a rethinking of the original plan. An operator inadvertently mixed hexamine with nitric acid, triggering an explosion: "This indicated clearly the hazard of permitting the two [mixing] operations to be carried on in the same building and, as a result, the five dissolving buildings [at HSAAP] were divided into three hexamine dissolving units and two ammonium nitrate dissolving units."³⁵ Buildings C-1, C-5, and C-9 were selected for mixing hexamine and acetic acid; Buildings C-3 and C-7 for nitric acid and ammonium nitrate. In the final plan implemented during World War II, all five Mixing Buildings had the capability to feed all ten lines.³⁶ A Tennessee Eastman spokesperson noted that a "more logical arrangement" would have been to centralize the two mixing operations in two separate facilities, but as the five Mixing Buildings "were under construction at the time . . . no other arrangement was feasible."³⁷ Although HSAAP did construct a separate building for mixing nitric acid and ammonium nitrate in 1944, a centralized hexamine mixing facility was not completed until after the Vietnam War. As a result of this last improvement, the original Mixing Buildings became obsolete, and plans are now underway to retire them

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completely from service.³⁸

With the rest of Line 9, Building C-9 began operation in November 1943. It remained in service until about April 1945, closing down a few months before the deactivation of the remainder of the line. Its shutdown was prompted by "improved operations [that] made possible the solution of all hexamine in two of the three available buildings."³⁹ Reactivated in the late 1960s for Vietnam War production, Building C-9 has not been in use since 1973. As there was little modification in the original hexamine mixing procedure, the building's construction, equipment, and process flow closely reflect World-War-II conditions.

Bordering a railroad track on the north, the flat-roofed building measures approximately 80 feet by 40 feet (see HAER Photo Nos. TN-10B-1, TN-10B-26 through TN-10B-28). It consists of two interconnected sections: a one-story storage area to the east and a two-story mixing house on the west. The storage area has brick walls and a metal-post and wood-frame structural system with cement flooring. The mixing house has an exposed reinforced-concrete frame with brick walls and slab floors and roof. The foundations for both sections are reinforced-concrete. All of the sash is industrial steel. As in all Line 9 buildings, the original glass lights have been replaced by shatter-proof, translucent fiber glass, eliminating a previous problem of glass-contamination in the manufactured explosive, which is prematurely sensitized by such foreign material.

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The storage area was used for receiving and storing 50-pound bags of hexamine, supplied by outside vendors. Unloaded from rail cars through an overhead metal door on the north side of the storage area, the hexamine was transferred to the second floor of the mixing house by a freight elevator, centrally spaced between the two sections of the building. During World War II, the acetic acid for dissolving the hexamine was manufactured at Plant A and delivered to Building C-9 in tank cars over the inter-plant railroad. In the 1950s, HSAPP replaced tank-car service with an above-ground pipeline connecting the acetic-acid manufacturing facilities with Plant B. During the Vietnam War, however, the installation phased out its acetic-acid manufacturing plant and began purchasing the material from outside vendors, thereby resuming tank-car delivery.

After arriving at Building C-9, the tank cars were emptied by a track-side pumping station into three stainless-steel storage tanks at the southeast corner of the building. (During World War II, wooden tanks were used because of a critical shortage of stainless steel.) From the storage tanks, the acid was pumped to the second floor of the building, which contained two stainless-steel "scale" tanks, one along the north wall and one along the south wall. Each scale tank was immediately adjacent and connected to a larger, top-agitated, stainless-steel "dissolving" tank, which protruded into the first-floor level. The scale tanks received acetic acid from the outside storage tanks and measured the liquid into their companion dissolving tanks, previously hand-loaded through a top hopper with hexamine. Since the hexamine

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was delivered in 50-pound bags, there was no need to weigh the material. During World War II, however, the hexamine was delivered in bulk form, and a pit scale in the center of the second floor was used to ensure accuracy. This scale has been removed and the "pit" filled in with cement.

After the dissolving tanks were charged with the proper proportions of acetic acid and hexamine, an operator activated the agitator on each tank, which thoroughly mixed the solution. Once uniformity was achieved, the material was pumped from the bottom of the dissolving tank into a companion stainless-steel storage tank on the first floor. These tanks in turn fed an outside above-ground pipeline, which carried the hexamine/acetic acid solution to the D Buildings for processing into RDX. Building C-9 retains its full complement of scale tanks, dissolving tanks, and storage tanks.

Building D-9 (Nitration Building)

The D Buildings house the central process in RDX production: the reaction of hexamine, nitric acid, ammonium nitrate, and acetic anhydride to form crude RDX and a waste solution of "spent acid." The process consists of a fairly complicated series of chemical reactions. In simplified form, however, it entails the breaking down, or "nitrolysis," of hexamine by nitric acid and ammonium nitrate in order to form the nitramine compound RDX (cyclotrimethylenetrinitramine, $C_3H_6O_6N_6$). The nitrolysis also liberates water, which would inhibit the reaction unless somehow "removed." The acetic anhydride serves

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this purpose by "taking up" the water and forming acetic acid, thereby driving the reaction to completion. For optimum results, the reaction requires a slight surplus of nitric acid.⁴⁰ This surplus, together with the acetic acid by-product, forms the "spent acid" solution.

In engineering a mass-production system for RDX, Tennessee Eastman faced two major challenges in the D Buildings. First, the formation reaction for RDX proceeds with great turbulence and rapidity, requiring a quick and thorough mixing of all ingredients. Second, the reaction must be maintained within a narrow temperature range (roughly 65-72 degrees Centigrade). Since the reaction is also exothermic in nature, it was necessary to devise a method of removing the excess heat. At its pilot plant, Tennessee Eastman solved both problems by designing a highly innovative reactor nicknamed a "jeep," which "was absolutely new in the explosives industry."⁴¹ The reactor consisted of a box-like, aluminum "funnel," which received the liquid ingredients and then, by means of a centrifugal pump, mixed and circulated the reactants through a long loop of jacketed, water-cooled, aluminum pipe with an outlet for the finished product.⁴² Previous reactors in the explosives industry had been designed for a "batch" process, whereby specific amounts of ingredients were introduced, reacted, and removed before a new batch could be formulated. The Tennessee Eastman reactor, however, permitted a constant flow of ingredients and product. It was the first "continuous" reactor in the industry, highly suited for a mass-production process.⁴³

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In the initial design of the D Buildings, the reactor loop, or "leg," consisted of 200 feet of three-inch diameter, Pyrex-glass tubing. Pyrex was a compromise material. Although it was susceptible to breakage, it took a higher polish than alternate, available materials, including aluminum and stainless steel. The degree of polish was critical, since the interior of the reactor leg was prone to coating, which clogged and shut down the reaction.⁴⁴ To accommodate a doubling of production quotas for RDX in the summer of 1943, the tube diameter was increased to four inches and its length to 360 feet (see HAER Photo No. TN-10B-32). Increased production also required a greater flow of ingredients into the reactor. This was accomplished by raising the height of the "head" tanks on the top of the D Buildings, which gravity-fed ingredients into the reactors. Increased height meant increased pressure, and the existing D Buildings were therefore reconstructed with a penthouse addition. Since Buildings D-9 and D-10 had not yet been completed, they were built with the penthouse and enlarged reactor legs as original features.⁴⁵ By the Vietnam War, the technology of stainless-steel polishing had sufficiently improved to permit replacement of the glass reactor legs with stainless-steel loops, eliminating the previous glass-breakage problem. Another reactor improvement of the Vietnam-War era was the introduction of an enlarged, water-jacketed, stainless-steel reactor funnel, which facilitated temperature control and increased production.

In its general configuration, Building D-9 consists of two major sections: a flat-roofed, brick structure with exposed reinforced-concrete frame to the

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north and an adjoining wood-trestle "pipe bridge" to the south (see HAER Photo Nos. TN-10B-2, TN-10-29 through TN-10B-31). Measuring approximately 40 feet by 75 feet, the brick section has two three-story wings to the north and south, flanking a central four-story core surmounted by a penthouse. A four-story stair tower is centrally located on the west elevation. The foundations and flooring are reinforced-concrete. The pipe bridge, which supports two looped reactor legs, is about two stories in height and about 160 feet in length. The interior of the brick structure is divided, north-south, into two mirror-image production units.

During the Vietnam War, Building D-9 received its ingredients through above-ground pipelines in the following ways: the nitric acid/ammonium nitrate solution came from a central mixing facility, Building 330, located in the western section of Plant B; the hexamine/acetic-acid solution came from one of the appropriate C Buildings, and the acetic anhydride solution came from a stainless-steel storage tank to the north of the building. This tank was in turn supplied through above-ground pipeline from the acetic-anhydride manufacturing complex at Plant A. Before the interplant pipeline was constructed in the 1950s, the acetic anhydride was shipped in by tank car and unloaded into a storage tank at the C Buildings, in the same manner as the acetic acid.

Originally, all three ingredients were pumped into separate, stainless-steel "scale" tanks on the first floor, which, in turn, supplied the "head" tanks in

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the penthouse (see HAER Photo No. TN-10B0-33). Since there were two production units in the building, there were two sets of scale tanks and head tanks. After World War II, however, the two scale tanks for acetic anhydride were replaced by a single tank located outside the building on the east elevation. This tank pumped acetic anhydride for both production units. From the feed tanks, the ingredients flowed through pre-set flow meters into the reactors on the third floor, passing first through a water-cooled heat exchanger, which regulated the temperature of the feeds. After circulating rapidly through the pipe-bridge reactor legs, the mixture exited into stainless-steel "hold-up" or "aging" tanks on the third floor, one for each reactor. In these vessels, the reaction came to completion.

At this stage, according to the original design, the process reverted to a batch procedure. Each of the hold-up tanks discharged into one of eight stainless-steel, top-agitated, steam-heated and water-cooled "simmer" tanks on the second floor (see HAER Photo No. TN-10B-3). After the addition of a small amount of "weak acid" solution (supplied by Building E-9, as will later be described) to control acidity levels, the mixture was heated to destroy undesirable by-products, and the resulting mixture was a solution of spent acid and RDX solids. A portion of the spent acid was decanted, filtered to remove RDX particles, and pumped to holding tanks outside Building E-9. The crude RDX-and-acid residue in the simmer tanks was then mixed with filtered water, agitated to create a slurry, and pumped through above-ground pipeline to Building E-9, where the product was "washed" to remove the acid. The use

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of a water-based slurry for "transporting" the product was an important innovation for two reasons. First, RDX is not readily soluble in water, which means that the material can be filtered out of the transport medium for various types of processing. Second, water reduces, or "desensitizes," the explosive qualities of RDX, permitting the transfer of the material from one processing station to another with a reasonable degree of safety.

During the Vietnam War, the batch procedure in the D Buildings was streamlined by the adoption of a continuous simmering process, whereby each hold-up tank discharged into a series of four interconnected simmer tanks on the second floor. The first tank heated the mixture, and the other three tanks gradually cooled it. From the last tank, the crude RDX slurry was pumped directly to Building E-9, eliminating the decanting and filtering steps. The improved process reduced time and labor, increasing D Building production by about 50 per cent.⁴⁶ With the exceptions of the head tanks, one reactor funnel, one simmer tank, and various pumps, Building D-9 retains its Vietnam-War-era production equipment.

Building E-9 (Washing Building)

Measuring approximately 32 feet by 64 feet, Building E-9 is a three-story, flat-roofed, brick structure with reinforced-concrete foundations, an exposed reinforced-concrete frame, and slab flooring (see HAER Photo Nos. TN-10B-4, TN-10B-34 through TN-10B-36). During both World War II and the Vietnam War,

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the building used essentially the same equipment and process flow to water-wash the crude RDX slurry from Building D-9, thereby removing the spent acid from the mixture. The main alteration concerned a series of spent-acid and wash-water tanks on the east and west elevations. Originally wood, they were replaced, beginning in 1945, by stainless-steel vessels more capable of withstanding the corrosive affects of acid.⁴⁷

Entering the third floor of Building E-9, the crude RDX slurry was pumped into a series of eight, top-agitated, false-bottom, stainless-steel "wash" tanks, the bottoms of which protruded into the second-floor level (se HAER Photo No. TN-10B-5). Under vacuum, the spent acid was sucked off the bottom of the tanks and delivered, by pumps on the first floor, to "receiver" tanks on the building's east elevation. Although the wash tanks were equipped with filtering mechanisms, a certain amount of RDX entered the receiver tanks with the spent acid. After a suitable holding period to allow the RDX in the solution to settle out (and eventually be recovered from the bottom of the receiver tanks), the spent acid was pumped into two larger storage tanks on the west elevation. From these tanks, the spent acid was eventually pumped to a series of "B" Buildings on the northern edge of the manufacturing area.⁴⁸ These buildings treated the spent acid to recover any remaining RDX, neutralized the nitric acid, and reconcentrated the acetic acid so that it could be used in the Area-A manufacturing program.

After the removal of the spent-acid solution, the wash tanks contained an RDX

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filtrate still contaminated with acid. To remove the remaining acid, the tanks were filled with filtered water and agitated to ensure thorough mixing. The "wash water," also known as "dilute liquor," was then sucked off the bottom of the wash tanks and delivered, by pumps on the first floor, to receiver tanks on the west elevation of the building (see HAER Photo No. TN-10B-6). From these tanks, the dilute liquor was eventually pumped to Building D-9 for use in the simmering process. This washing and vacuum-filtration procedure was repeated until the acidity of the RDX solution was reduced to a specified level. After the last washing, the RDX was once again slurried up with filtered water and pumped through above-ground pipeline to Building G-9 for further purification. Except for the removal of one wash tank, Building E-9 retains its full complement of Vietnam-War-era equipment.

Building G-9 (Purification Building)

Measuring approximately 50 feet square, Building G-9 is a three-story, brick-and-reinforced-concrete structure, similar in construction to Building E-9 (see HAER Photo Nos. TN-10B-7, TN-10B-37 through TN-10B-39). In this structure, the RDX-purification process reached completion. Although the exterior surfaces of the crude RDX was washed clean of spent acid in the E Building, the material still had a small amount of acid occluded, or trapped, within its crystalline structure. In the G Buildings, this acid was liberated by dissolving the RDX in a solvent, which was then distilled off so that the RDX could recrystallize in acid-free form. The principal changes in the

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operation concerned the nature of the solvent.

During World War II, the purification process relied primarily on acetone, which presented two major drawbacks. First, acetone created a substantial fire hazard because of its high volatility and flammability. Second, this particular solvent combines readily with water. Although most of the water in the RDX slurry was immediately removed, on the third floor, under vacuum in cloth-lined, wood-box, filtering devices known as "nutsches" (see HAER Photo No. TN-10B-41), the RDX was deliberately left quite wet when it was hand-shoveled out of the nutsches and mixed with acetone in the "dissolver" tanks. If more of the water had been removed, the RDX would have been transformed into a sensitized explosive, prohibiting further processing. By leaving the RDX wet, however, the acetone was unavoidably contaminated with water (even after distillation), requiring an elaborate purification process in a separate building so that the solvent could be recycled.

Toward the end of World War II, Tennessee Eastman solved both problems by replacing acetone with cyclohexanone. This solvent has a higher flashpoint than acetone and is also less miscible with water. The substitution reduced the fire hazard, and also eliminated the need for outside solvent-purification. The major equipment change was the relocation of solvent condensers. In the acetone process, the primary condensers were suspended from the ceiling on the second floor. They received acetone vapor from distillation apparatus on the first floor, liquified the vapor, and then

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pumped the acetone to outside storage tanks so that the solvent could be pumped to a separate purification building. In the cyclohexanone process, outside purification was no longer necessary, and the solvent could be immediately recycled into the dissolver tanks. To accomplish this, the condensers were relocated to the ceiling of the third floor, permitting the cyclohexanone to flow by gravity directly into the dissolver tanks located on that level (see HAER Photo No. TN-10B-8). Although several of the lines were converted to cyclohexanone before the end of World War II, Building G-9 was not altered until its reactivation for the Vietnam War in the late 1960s.⁴⁹

Another important improvement during World War II was the elimination of the time-consuming, nutsche-filtration step on the third floor of the G Buildings. It was determined that a higher quality RDX crystal could be produced by introducing the full RDX slurry directly into the dissolver tanks. The resulting crystals displayed a more uniform and more desirable particle size. Previously, it had been necessary to "grind" the crystals to a specific "grist" in the H Buildings. But the new process in the G Buildings made this step unnecessary.⁵⁰

After remodeling for Vietnam-War production, Building G-9 contained four self-contained, dissolver-and-distillation units. Each unit consisted of a steam-heated and water-cooled, stainless-steel dissolver tank on the third floor; a steam-heated and water-cooled, stainless-steel "still" tank on the second floor, and a water-cooled, tube condenser on the third floor (see HAER

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Photo NO. TN-10B-40). Although there were only four production units, the Building contained a total of five third-floor condensers, one serving as a back-up for the entire system. Both the dissolver tanks and still tanks were top-agitated, with the tank bottoms protruding into the floor level below. Pumped from Building E-9, the RDX slurry entered the top of the third-floor dissolver tanks, where it was simmered and agitated with cyclohexanone to ensure that the RDX was thoroughly dissolved by the solvent. The solution was then gravity-dropped from the bottom of the dissolvers into the second-floor still tanks, passing first through stainless-steel "screen pots" (filters) mounted on top of the still tanks (see HAER Photo No. TN-10B-9). The screen pots removed any foreign matter that might sensitize the explosive.

In the still tanks, the solution was heated and agitated to drive off the cyclohexanone, which collected in the the third-floor condensers for recycling in the dissolvers. After elimination of the solvent, the recrystallized RDX was slurried up with filtered water and transferred, by pumps on the first floor, through above-ground pipeline to Building H-9 for final "de-watering" (see HAER Photo No. TN-10B-10). Building G-9 still retains its full complement of Vietnam-War-era processing equipment.

Building H-9 (Grinding Building)

The H Buildings concluded the preparation of RDX and commenced the manufacture of Composition B. This entailed two major steps in the following sequence:

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(1) dewatering the RDX by vacuum filtration to produce a sensitized explosive, and (2) mechanically grinding the RDX in "colloid mills" to achieve a specified "grist," or particle size. The grist affected the viscosity of Composition B when it was later melted and poured into ordnance at specialized "loading plants." As a result of process improvements in the G Buildings during World War II, the grinding step was eliminated, and the H Buildings were subsequently renamed "Dewatering Buildings." During the Vietnam War, the dewatering process was significantly streamlined by the adoption of a new vacuum-filtration system. In the old method, the RDX slurry was poured into cloth-lined, wood-box nutsches, each with a vacuum hose attached to the bottom. In the new method, an overhead cluster of ten, cloth-wrapped, perforated, stainless-steel, vacuum probes was lowered into a cloth-lined, stainless-steel nutsche to draw off the water (see HAER Photo Nos. TN.-10B-13, TN-10B-46).

Because the dewatering process produced a sensitized explosive, the H Buildings are isolated from the previous buildings in the line by an earth-filled wood barricade (see HAER Photo NO. TN-10B-54). The buildings themselves make use of light, wood-frame, "blow-out" construction, designed to minimize site-damage from a possible explosion by quickly diffusing the blast. (All subsequent buildings in the line display similar construction for the same reason). Measuring approximately 48 feet by 32 feet, Building H-9 is a flat-roofed, one-and-two-story structure with a free-standing, one-story "electrical room" at its northwest corner and a small "shipping patio"

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adjoining its south (one-story) elevation (see HAER Photo Nos. TN-10B-11, TN-10B-12, TN-10B-42 through TN-10B-45). All sections have reinforced-concrete foundations, slab floors, and asbestos-shingle siding. Originally the electrical room was located at the southwest corner and the shipping area extended about 40 feet further to the south. In the late 1960s, however, the building was shortened and remodeled to its present configuration to increase the "safety distance" from the Incorporation Buildings next in line.

During the Vietnam War, the RDX slurry from Building G-9 entered the north, or two-story, section of the building, flowing into three elevated, top-agitated, stainless-steel "receiver" tanks arrayed along the north wall. Each receiver tank was equipped with a top-mounted, screen pot (filter) that removed any foreign matter that might sensitize the explosive. The receiver tanks agitated the slurry and gravity-dropped it through a single overhead line into ten cloth-lined, stainless-steel nutsches, each positioned under a cluster of vacuum probes attached to an overhead suction line, which reduced the water content of the RDX to about 11 per cent and transferred the waste water to an outside settling tank on the building's north elevation. After dewatering, the nutsches were weighed on platform scales to ensure that each contained a prescribed amount of RDX. They were then hand-wheeled on battery-operated lift trucks through the shipping patio to the wheeling ramps for delivery to the Incorporation Buildings (see HAER Photo Nos. TN-10B-45, TN-10B-53). In the original World-War-II procedure, the RDX slurry flowed from the receiver

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tanks through colloid mills into a single floor-mounted holding tank, from which it was distributed by an overhead line into the nutsches for filtration.

The holding tank, however, was eliminated with the grinding procedure. Currently, Building H-9 is missing several of its probe units and all of its nutsches. The remainder of the Vietnam-War-era equipment is in place.

Building O-9 (Laboratory)

Equidistantly spaced between each pair of H Buildings are five Laboratories, each serving the two neighboring lines. Sheltered by earth-filled, wood-frame barricades on all elevations except the south, the Laboratories ran quality control tests on RDX and Composition B, checking moisture, grist, acidity, and impact sensitivity (see HAER Photo No. TN-10B-14). Building O-9 served Lines 9 and 10. Measuring about 50 feet by 55 feet, it is a one-story, gable-roof, wood-frame structure with reinforced-concrete foundations, slab flooring, and asbestos-shingle siding and roofing (see HAER Photo NO. TN-10B-52). The northern third of the building is given over to toilets and a medical examining room. The rest of the interior space is divided into a chemical testing laboratory with adjoining office and a small impact-testing room in the building's southeast corner. Interior partitions are plaster-on-wood-stud, except for the impact-testing room, which is set off by concrete blast walls. For safety purposes, each interior space has its own exit to the outside. There is no longer any testing equipment in the building.

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Building K-9 (TNT Opening Building)

Measuring approximately 30 feet by 32 feet, Building K-9 is a flat-roofed, one-story, wood-frame structure with reinforced-concrete foundations, slab flooring, and asbestos-shingle siding (see HAER Photo Nos. TN-10B-16, TN-10B-49). It supplied the four Incorporation Buildings of Line 9 with TNT, which was trucked in from other plants and unloaded at a concrete dock on the building's south elevation. The TNT handling process experienced only slight modification after World War II. Shipped to Building K-9 in 50-pound lots, the TNT was unpacked from its original fiberboard boxes, and each lot transferred to a cylindrical fiberboard container. Using a battery-operated lift truck, an operator delivered the loaded pallets to the Incorporation Buildings, which were linked to the north elevation of Building K-9 by a wood-frame, gable-roof, wheeling ramp. During the Vietnam War, the TNT arrived at Building K-9 in 55-pound lots, which were unloaded into stainless-steel "melt" kettles, 10 lots to each kettle. Operators then transported the kettles to the Incorporation Buildings in the original manner.

Building L-9 (Incorporation Building, similar to Buildings I-9, J-9, M-9)

Composition B was produced by "incorporating," or blending RDX (60%), TNT (40%), and wax (about 1%). To limit the amount of explosives concentrated in any one place, the incorporation process in each line was divided among four similar, widely spaced buildings: "I," "J," "L," and "M." On the north,

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these buildings were connected by covered, wood-frame wheeling ramps to the H and K Buildings of their particular line, which supplied, respectively, RDX and TNT. (None of the available process descriptions state how the wax was delivered.) On the south, the Incorporation Buildings were connected by wheeling ramps to the N Building next in line, which packaged the Composition B for shipment to outside "loading plants," where the explosive was melted and poured into ordnance. On the east and west, each of the Incorporation Buildings was isolated from other structures by earth-filled, wood-frame barricades.

Building L-9 is representative of the other Incorporation Buildings in the line. Measuring approximately 50 feet by 96 feet, it is a flat-roofed, one-story, wood-frame structure with reinforced-concrete foundations, slab-flooring, and asbestos-shingle siding (see HAER Photo Nos. TN-10B-46, TN-10B-48, TN-10B-50). The structure contained two mirror-image production lines that occupied the east and west halves of the building. The interior space is divided into two distinct sections. At the north end (extending for about 16 feet from the north wall), there is a raised, mezzanine level over a "basement." The basement contained two Troy-Enberg, vertical steam engines (one for each line), which, by means of chain-driven gears and shafts, supplied power for the mixing and casting procedures on the level immediately above (see HAER Photo Nos. TN-10B-21, TN-10B-18, TN-10B-19, TN-10B-51). The rest of the building is a one-story open space, which contained, along the east and west walls, an inclined conveyor supported on concrete piers (see

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HAER Photo No. TN-10B-20). Power for each conveyor was shaft-supplied at the south end by an individual electric motor, mounted outside the building (see HAER Photo No. TN-10B-17). The use of steam engines and outside motors was intended to reduce fire hazard and risk of explosion.

The operation of Building L-9 changed relatively little from World War II to the Vietnam War. Wheeled in from the Building K-9, pre-weighed lots of TNT were melted in a movable, jacketed, steam-heated, steel "melt" kettle on the building's mezzanine. After the TNT was melted, the kettle was moved into position and hand-tilted by two operators into a stationary, jacketed, steam-heated, steel "incorporation" kettle, which was agitated by a central rotor, powered by the steam engine in the basement. RDX was then hand-shoveled into the kettle, followed by the hand-pouring, from a small bucket, of a pre-weighed amount of melted wax, which completed the blend of ingredients.

When the Composition B was suitable mixed, the incorporation kettle was hydraulically tilted so that the material flowed into an adjacent, rotor-agitated, steel, "hold-up" kettle," which, in turn, gravity-fed a rotor-agitated, bottom-perforated, steel "casting kettle," suspended immediately below. The casting kettle was cantilevered out from the mezzanine level so that it was situated directly above the lower end of an inclined, moving, stainless-steel conveyor belt. Extruded from the bottom of the casting pot, viscid droplets of composition B fell onto the conveyor belt,

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cooling into solid pellets that dropped off the upper end of the conveyor into shipping boxes, which were transported to Building N-9 for final packaging. To ensure a continuous flow of product, each hold-up kettle was paired with two incorporation kettles, which alternated batches.

The major modification to the incorporation process was the addition of a forced-air ventilation system, added in 1944, and updated during the Vietnam War.⁵¹ As part of this system, metal ductwork was installed over the various kettles and conveyors, and a small fanhouse was constructed on top of the building. Currently, the building's conveyor systems are disassembled and the various melt kettles are missing. The steam engines, incorporation kettles, hold-up kettles, and casting kettles are still in place.

Building N-9 (Nailing Building)

Building N-9 concludes the manufacture of Composition B by overseeing final packaging arrangements. Measuring approximately 48 feet by 40 feet, the building is a flat-roofed, wood-frame, one-story structure with a two-story elevator section in the northeast corner, a concrete loading dock at the southeast corner, and a gable-roofed "receiving shed" at the northwest corner, which is linked to the Incorporation Buildings by a wood-frame, gable-roofed wheeling ramp. Sheltered by earth-filled, wood-frame barricades on the east and west, the building has reinforced-concrete foundations, slab flooring, and asbestos-shingle siding (see HAER Photo Nos. TN-10B-22, TN-10B-23, TN-10B-49).

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In the spring of 1945, a Tennessee Eastman spokesperson noted "a major change" in the final packaging operation for Composition B:

The original plan included a loading station at the end of each [cooling] belt [in the Incorporation Buildings]. [Wood] boxes of Composition "B", with the lids laid on loosely, were transferred to pallets and moved to the Nailing Buildings, where they were placed individually on the conveyor lines to be nailed and banded. The boxes then had to be returned to a pallet for transfer to the [buildings'] loading docks [for truck delivery to the installation's magazine area or to outside ordnance plants]. [In] the new system . . . a tote box of sufficient size to hold a complete Composition "B" batch is placed beneath a chute at the end of the cooling belts [in the Incorporation Buildings]. The tote box is then transferred by an electrical transport truck [via the wheeling ramps] to the Nailing Buildings where it is placed on an elevator actuated by a hydraulic ram. In the elevated position, the tote box can be discharged by opening a wooden slide allowing the batch to pour into a hopper inside the Nailing Building. Composition "B" boxes are loaded from this hopper and moved directly down a conveyor to the banding [and nailing] stations. . . . By this means, individual, loaded Composition "B" boxes are handled only one time instead of three times as in the original plan, and it will be possible to substitute 35 women operators for 140 men operators now engaged in the handling of boxes.⁵²

The adoption of the new system, which remained substantially the same through the Vietnam War, necessitated the remodeling of the N Buildings (previously one-story structures) with a two-story section to accommodate the elevator for the tote boxes. Building N-9 retains the elevator equipment and metal-roller conveyors for handling the boxed explosive, but lacks nailing and banding apparatus.

NOTES

1. The two sections of HSAAP were officially designated as "Plant A" and "Plant B," but ever since World War II, they have commonly been referred to as "Area A" and "Area B." Originally, the installation itself was known as "Holston Ordnance Works." The present name, Holston Army

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Ammunition Plant (HSAAP), dates from 1963. It is used throughout this report for the sake of brevity and clarity.

2. None of the ten lines contain an "F Building." This designation was reserved for five "Change Houses" located just north of the manufacturing area. In these buildings, operators began their shift by exchanging their street clothes for work uniforms.
3. Tennessee Eastman Corporation, "Historical Report of Holston Ordnance Works for the Eleventh Period, October 3, 1943 Through October 30, 1943," p. 2, unpublished, Box A77, Record Group 156, Records of the Office of the Chief of Ordnance, National Archives, Suitland, MD; hereafter cited as RG 156, with the appropriate box number.
4. Tennessee Eastman Corporation, Historical Report of Holston Ordnance Works for the Eighth Period, July 15, 1945 Through August 11, 1945," p. 1, Box A79, RG 156; Susan S. Pridemore, "Holston Army Ammunition Plant, Unit History, Annual Supplement- CY 1968," p. 12, unpublished, HSAAP Archives; Pridemore, "Holston Army Ammunition Plant, Unit History, Fiscal Year 1973, Annual Supplement," p. 25, unpublished, HSAAP Archives.
5. On the formation of the NDRC, see Baxter, pp. 14-25, 119-123, 451.
6. The British work with RDX during the 1930s is described in W. H. Simmons, "The Manufacture of R.D.X. in Great Britain," Industrial Chemist, 24 (July, 1948), 429-430; R. C. Burton, "The Origin of Holston Army Ammunition Plant," Speech before Rotary Club of Kingsport, Tenn., Sept. 10, 1975 (Kingsport: n. pub., 1975), n.p., in Palmer Room, Kingsport Public Library. On the use of RDX in naval ordnance, see Buford Rowland and William B. Boyd, U.S. Navy Bureau of Ordnance in World War II (Washington, D.C.: U.S. Government Printing Office, n.d.), pp. 204-207; Constance McLaughlin Green and others, The Ordnance Department: Planning Munitions For War (Washington, D.C.: Office of the Chief of Military History, Department of the Army, 1955), p. 463.
7. Buford and Boyd, p. 206.
8. Ellen Crawford, "Full Story of HOW Product," Kingsport Times-News, December 9, 1945. The standard military history of American munitions'-plant construction during World War II notes: "super-explosives from the Holston plant were crucially important in sweeping Hitler's U-boats from the Atlantic and in pulverizing German war industries" (Lenore Fine and Jesse A. Remington, The Corps of Engineers: Construction in the United States [Washington, D.C.: Office of the Chief of Military History, United States Army, 1972], p. 596).
9. The use of the Woolwich method at the Bridgewater plant is discussed in Simmons, "The Manufacture of R.D.X. in Great Britain," Industrial

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Chemist, 24 (July 1948), (August 1948), (September 1948), 429-432, 530-544, 593-601. On the method's nitric-acid requirements, Simmons writes: "One of the most striking features of the Woolwich process for the manufacture of R.D.X. is the size of the acid plant necessary. . . . It had been learnt by experience that the production of 1 ton of R.D.X. required the addition of 0.86 tons hexamine to 11 tons of concentrated nitric acid. Of this 11 tons about 5 tons could be recovered as weak acid . . . and rather more than 4 tons by absorption of the nitrous fume produced in the process. Allowing reasonable process losses, it was clear that for each ton of R.D.X. there would be about 9 tons of weak nitric to reconcentrate, and rather more than 2 tons of new strong nitric acid to reduce" (p. 430). The initial involvement of the NRDC with RDX research is discussed in Baxter, pp. 255-256.

10. Bachmann's initial response to the RDX project is noted in Baxter, p. 256. The first published description of the Bachmann method is found in W. E. Bachmann and John C. Sheehan, "A New Method of Preparing the High Explosive RDX," Journal of American Chemical Society, 71 (May 1949), 1842-1845. The method's pros and cons are analyzed in Burton, n.p.
11. On Tennessee Eastman's production of cellulose acetate, see "Eastman Corp. Defies Slump," Knoxville Journal, June 4, 1933; "Chemical Wonderland," Oilways, 14 (June 1948), 1-5. The acetic-acid recovery problems involved in the manufacture of cellulose acetate are discussed in Alfred George Lipscomb, Cellulose Acetate (London: Ernest Benn Limited, 1933), pp. 77-101. For Tennessee Eastman's pilot-project work, see Burton, n.p. It should be noted that HSAAP was not the first RDX plant built in the United States. That honor belonged to the Wabash River Ordnance Works, a Woolwich-type facility constructed at Newport, Indiana during 1941-1943. Boasting the world's largest nitric-acid works, the Wabash River plant accounted for about one-tenth of American RDX production during World War II; its RDX lines were completely dismantled in the 1970s. See Baxter, p. 257.; William Voight, Jr., "The Ordnance Organization in World War II," pp. 312-315, unpublished, 1945, on microfiche, in AMCCOM Historical Office, Rock Island Arsenal; C. H. Carter, Jr. and others, "History of the Powder and Explosives Section, March 1943 to September 1945," unpublished report prepared for Ammunition Division, Office of the Chief of Ordnance, 1945, pp. 9-11, Appendix IV-33, on microfiche, AMCCOM Historical Office; "Holston Army Ammunition Plant, Historical Monograph Covering the Period 1 July 1942 Through 30 June 1963," unpublished report prepared by Holston Defense Corporation, 1963, p. 22, in Holston Defense Corporation Archives, HSAAP.
12. Voight, pp. 132-133; Burton, n.p.
13. Fine and Remington, pp. 134-137.
14. "It's a Long Way from a Pasture to Ammo Plant," Kingsport News, November

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- 14, 1968. The thirty-eight buildings within the boundaries of HSAAP as of October 1944 are inventoried in "Industrial Facilities Inventory, Holston Ordnance Works," vol. 2, Plant B, Part I, Section 9, n.p.; Part II, Section 4, n.p., unpublished report prepared by U.S. Army Corps of Engineers, Office of the District Engineer, Nashville, Tenn., 1944, in AMCCOM Historical Office.
15. Harry Englander, Building Holston Ordnance Works (New York: Fraser-Brace Engineering Co., Inc. 1946), p. 15, in Holston Defense Corporation Archives, HSAAP. See also Fine and Remington, p. 517.
 16. The description of the various contracts is from "Construction Speeded Output of 'RDX,'" Engineering News-Record, 64 (July 25, 1946), 65. Fraser-Brace's work on the Weldon Springs plant is noted in Englander, p. 19. On Charles T. Main, Inc. and Camp Edwards, see Fine and Remington, p. 211.
 17. Fine and Remington, p. 595.
 18. Robert O. Bengis, "Super Explosive Program, RDX and its Components A, B, and C," vol. 2, n.p., unpublished, 1945, Box 333, Record Group 319, Records of the Army Staff, National Archives, Washington, D.C ; hereafter cited as RG 139, with the appropriate box number.
 19. Englander, p. 47.
 20. "Industrial Facilities Inventory, Holston Ordnance Works," vols. 1, 2, 3, unpublished report prepared by U. S. Army Corps of Engineers, Office of the District Engineer, Nashville, Tennessee, 1944, HSAAP Archives.
 21. "Construction Speeded Output of 'RDX'" 67. Immediately after Pearl Harbor the Army Ordnance Department laid down strict rules for future munitions plant construction: "There is no excuse for masonry structures . . . where a light frame structure will serve the purpose. There is no excuse for the use of expensive materials where less costly ones will serve the purpose for the period of time for which the construction is being provided." By the spring of 1942, however, the nation was experiencing a critical lumber shortage which prompted Ordnance construction supervisors to permit the substitution of brick for wood "where the difference in cost and completion time was not excessive." On this matter of building materials, see Fine and Remington, pp. 517, 547.
 22. Burton, n.p.; J. T. Bearden, "A Short History of HDC," unpublished, 1970, pp. 4-7, Holston Defense Corporation Archives, HSAAP; Bachmann and Sheehan, 1842-1845.
 23. Burton, n.p.

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24. Burton, n.p.
25. Burton, n.p.; Bearden, p. 9.
26. "Holston Army Ammunition Plant Historical Monograph," pp. 11-13; R. C. Burton and H. D. McNeeley, "Progress Report on Processes and Equipment, Holston Ordnance Works," p. 14, unpublished, October 2, 1944, Box A81, RG 156.
27. Susan S. Pridemore, "Holston Army Ammunition Plant, Unit History, 1943-1967," p. 5, unpublished, 1968, HSAAP Archives; "Holston Army Ammunition Plant Historical Monograph," p. 17.
28. The initial discovery of HMX is noted in Bachmann and Sheehan, 1844. The pilot production of the material at HSAAP during World War II is discussed in Carter, p. 47, Appendix IV-42, 43. On HMX production during the 1950's, see "Holston Army Ammunition Plant Historical Monograph," pp. 2. 19; Pridemore, p. 6.
29. R. J. Hammond, "Profile on Munitions, 1950-1977," unpublished, n.d., pp. 82-82, microfiche in AMCCOM Historical Office; "\$30 Million Holston Ammo Plant," undated newspaper clipping in Kingsport Industries File, Palmer Room, Kingsport Public Library; Pridemore, pp. 12-13, "Annual Unit History Holston Army Ammunition Plant, 1975-1976," p. 9, unpublished, HSAAP Archives.
30. See the following unpublished reports in HSAAP Archives: "Annual Unit History, 1975-1976," p. 8; "Annual Historical Review, 1977-1978," p. 14; "Annual Historical Review, 1978-1979," p. 13; "Annual Historical Review, 1979-1980," p. 14; "Annual Historical Review, 1980-1981," p. 13.
31. The description of the line's "existing" technology reflects conditions as of December 1985, when the author toured the facility under the escort of Ned Stacy and Cinetker Ryans, production operatives on the staff of Holston Defense Corporation. The discussion of Vietnam-War-era procedures relies heavily on information supplied by these gentlemen. For World-War-II practices, the following unpublished reports prepared by Tennessee Eastman Corporation (RG 156, Box A79) were especially valuable sources of information: "Historical Report of Holston Ordnance Works for the First Period January 28, 1945"; "Historical Report of Holston Ordnance Works for the Second Period February 24, 1945 to March 24, 1945"; "Historical Report of Holston Ordnance Works for the Third Period February 24, 1945 to March 24, 1945"; "Historical Report of Holston Ordnance Works for the Fourth Period March 25 to April 21, 1945"; "Historical Report of Holston Ordnance Works for the Fifth Period April 22, 1945 to May 19, 1945"; "Historical Report of Holston Ordnance Works for the Sixth Period May 20, 1945 to June 16, 1945"; "Historical Report of Holston Ordnance Works for the Seventh Period June 17, 1945 to July

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14, 1945"; "Historical Report of Holston Ordnance Works for the Eighth Period July 15, 1945 to August 11, 1945"; "Historical Report of Holston Ordnance Works for the Ninth Period August 12, 1945 to September 8, 1945."

32. For a description of these auxilliary technologies, see Jeffrey A. Hess and Robert C. Mack "Historic Properties Report Holston Army Ammunition Plant, Kingsport, Tennessee," unpublished, prepared by MacDonald and Mack Partnership and Building Technology Incorporated for the Historic American Engineering Record, National Park Service, Department of the Interior, 1985. The report, with accompanying inventory cards, is filed as field records in the Prints and Photographs Division, Library of Congress, under HAER No. TN-10.
33. "On February 7, 1942, Dr. Bachmann and his assistants visited Kingsport upon request of T[ennessee] E[astman] C[orporation] and advised the personnel on technical operating procedure. Among other suggestions, he advised making a solution of hexamine in acetic acid and also a solution of ammonium nitrate in 98% nitric acid, the latter solution being one Bachmann used in experiments on August 14, 1941. On February 11, 1942, Bachmann carried out an experiment using such solutions at Kingsport and obtained an exceptionally high quality product and in good yield" (Bengis, vol. 1, n.p. The experimental work leading to the development of concurrent liquid feeds is also discussed in Tennessee Eastman Corporation, "Progress Report RDX Experimentation, Period Jan. 20, 1942, to March 7, 1942 (Report No. EWO-142-1)," unpublished, 1942, Box A80, RG 156 (see Section VIII, entitled "Process Development").
34. Tennessee Eastman Corporation, "Progress Report on Processes and Equipment," p. 2, unpublished, October 2, 1944, Box A81, RG 156.
35. Tennessee Eastman Corporation, "Progress Report," October 2, 1944, p. 2.
36. Tennessee Eastman Corporation, "Historical Report for the Fourth Period March 25, 1945 to April 21, 1945," p. 23, unpublished, Box 179, RG 156.
37. Tennessee Eastman Corporation, "Progress Report," October 2, 1944, p. 2.
38. Located west of the RDX manufacturing district in the "acid area," the centralized nitric acid/ammonium nitrate mix facility is known as Building 330. For details of its operation, see Carter, p. 49, Appendix IV-49, 50, 51. Completed in 1975, the central hexamine mixing facility (Building 151) is located to the north of Building C-3. Buildings C-3 and C-5 are still used as distribution and storage facilities for the hexamine/acetic acid solution.
39. "Historical Report, March 25, 1945 to April 21, 1945," p. 24; Tennessee Eastman Corporation, "Progress Report on Processes and Equipment," p. 1,

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unpublished, May 1, 1945, Box A81, RG 156.

40. The chemical reaction producing RDX may be summarized as follows:
$$\text{C}_6\text{H}_{12}\text{N}_4 \text{ [hexamine]} + 4\text{HNO}_3 \text{ [nitric acid]} + 2\text{NH}_4\text{NO}_3 \text{ [ammonium nitrate]} + 6(\text{CH}_3\text{CO})_2 \text{ [acetic anhydride]} = 2\text{RDX} + 12\text{CH}_3\text{COOH} \text{ [acetic acid]};$$
see Kirk-Othmer, Encyclopedia of Chemical Technology, vol. 9, 3rd ed., (New York: John Wiley & Sons, 1980), p. 582. The role of the acetic anhydride is explained in Burton, n.p. On the need for a nitric acid surplus, see "Progress Report RDX Experimentation, Section VIII," pp. 6-7.
41. Bengis, vol. 2, n.p.
42. The innovative reactor is described in "Progress Report RDX Experimentation (Section IV, Improvements)," p. 15.
43. On the distinctions between continuous and batch reactors, see Kirk-Othmer, vol. 19, ("Reactor Technology"), pp. 880-883.
44. The coating problem is discussed in Bearden, p.6.
45. "Progress Report," October 2, 1944, pp. 3-4; Bengis, vol. 3, n.p.
46. Pridemore, "Holston Army Ammunition Plant Unit History, 1964-1967," p. 24.
47. The replacement of the wood tanks by stainless-steel vessels is noted in Tennessee Eastman Corporation, "Historical Report of Holston Ordnance Works for the Third Period February 24, 1945 to March 24, 1945," p. 41, unpublished, Box A79, RG 156.
48. The spent-acid solution also contained "a considerable amount of RDX, which, during World War II, was destroyed in the B Buildings; see "Progress Report," October 2, 1944, pp. 17-18. After the war, explosive-recovery procedures were adopted in the B Buildings.
49. The development and implementation of the cyclohexanone process during World War II is discussed in Bengis, vol. 3, n.p. and the following unpublished reports prepared by Tennessee Eastman Corporation (RG 156): "Historical Report of Holston Ordnance Works for the Seventh Period June 11, 1944 to July 8, 1944, p. 36 (Box A78); "Historical Report of Holston Ordnance Works for the Tenth Period September 3, 1944 to September 30, 1944," p. 45 (Box A78); "Progress Report on Processes and Equipment," pp. 5-6, May 1, 1945 (Box A81).
50. On the elimination of the filtration and grinding procedures, see "Progress Report," October 2, 1944, p. 8; Tennessee Eastman Corporation, "Historical Report of Holston Ordnance Works for the Thirteenth Period November 28, 1943 Through December 25, 1943," p. 4, unpublished, Box A77 RG 156. It should be noted that the replacement of acetone with

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cyclohexanone also improved grist control.

51. "Progress Report," October 2, 1944, p. 13.
52. "Progress Report," May 1, 1945, pp. 11-14.

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Drawings

Holston Army Amunition Plant. Area B, Arrangement of Kettles and Drive Plan, Buildings I, J, L, & M - Lines 9 & 10. March 14, 1967; revised November 14, 1967, January 3, 1968. Delineator: Unknown. Drawing # 7651-1009.456.

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Holston Army Ammunition Plant, Holston Defense Corporation. Building Location Plan, Areas A & B. September 8, 1970. Delineator: R. C. G. Drawing # 7651-212/1226.03.

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_____. Sections Showing Equipment, Building "G". July 25, 1942. Delineator: E. E. Ellis. Drawing # 7651-1007-213.

PROJECT INFORMATION

This project was part of a program initiated through a memorandum of agreement between the National Park Service and the U.S. Department of the Army. Stanley J. Fried, Chief, Real Estate Branch of Headquarters DARCOM, and Dr.

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Robert J. Kapsch, Chief of the Historic American Buildings Survey/Historic American Engineering Record, were program directors. Sally Kress Tompkins of HABS/HAER was program manager, and Robie S. Lange of HABS/HAER was project manager. Building Technology Incorporated, Silver Spring, Maryland, under the direction of William A. Brenner, acted as primary contractor, and MacDonald and Mack Partnership, Minneapolis, was a major subcontractor. The project included a survey of historic properties at Holston Army Ammunition Plant, as well as preparation of an historic properties report and HAER documentation for 13 buildings. The survey, report, and documentation were completed by Jeffrey A. Hess, historian, Minneapolis and Robert C. Mack, architect, Minneapolis. The photographs were taken by Robert A. Ryan and Bruce A. Harms of Dennett Muessig, Ryan, and Associates, Ltd., Iowa City, Iowa. Drawings were produced by Robert Ferguson of MacDonald and Mack Partnership, Minneapolis and John Palmer Low, Minneapolis.